CHAPTER 2
ARCTIC AND SUBARCTIC REGIONS

2-1. Introduction

a. The Arctic and Subarctic may be defined in several different ways, depending on whether they are looked at from the point of view of astronomy, botany, physics, climatology, ocean navigation or other specialized field. For engineering, the Arctic and Subarctic are best defined on basis of the prevailing air temperature conditions. Definitions based on air temperature are given in paragraphs 1-4a(l) and 1-4a(2). Figure 2-1 shows the limits of the Arctic and Subarctic in accordance with these definitions, together with the northern limit of trees.

b. Climatic data for all stations that report to the U.S. National Weather Service are available from the U.S. Department of Commerce, National Weather Records Center, Asheville, North Carolina. In addition, climatic data for a large number of sites are given in TM 5-785/NAVFAC P-89/AFM 8829. For foreign countries, attempts should be made to obtain climatic data from their respective national climatic centers. Department of Defense agencies should request additional climatic information through the U.S. Air Force Environmental Technical Applications Center (ETAC), Scott Air Force Base, Illinois. Included in data obtainable through ETAC are weather records for all military airfields.

c. Climatological, ground temperature and soil data have been obtained from the 21 locations in Alaska and Canada that are shown in figure 2-2.

d. Detailed records for Canadian observation stations are available from Atmospheric Environment Service, Department of the Environment Canada, Toronto.

e. Some specific features of these regions of significance to engineering are outlined in the remainder of this chapter.

2-2. Temperature conditions

a. As may be seen in figures 2-3 and 2-4, temperatures decrease generally from south to north, although not strictly according to latitude. On both continents, the lowest mean annual temperature is about 5°F. Appendix A presents some general information about freezing and thawing index data from the two continents.

b. Air temperature records for some arctic and subarctic stations may not be of sufficient duration to permit determination of design freezing or thawing indexes on the basis of 30 years of record. For pavement design, as explained in paragraphs 1-4c(6) and 14c(7), the extreme values in 10 years of record may be used. For foundations of average permanent structures, the ratios of design to mean indexes determined at the closest stations that do have 30 years of record may usually be employed for estimating such design indexes at stations that have means based on at least 10 years of record.

2-3. Precipitation snow cover and snow loads

a. Annual precipitation is mostly very light in the Arctic, much of it falling as snow. Considerably heavier precipitation falls in certain parts of the Subarctic that are under the influence of maritime storm paths. TM 852-7/AFM 88-19, Chap. 7 presents hydrologic criteria, together with general information on icing and special design considerations, for arctic and subarctic conditions. Figure 2-5 shows mean monthly and annual precipitation at selected stations.

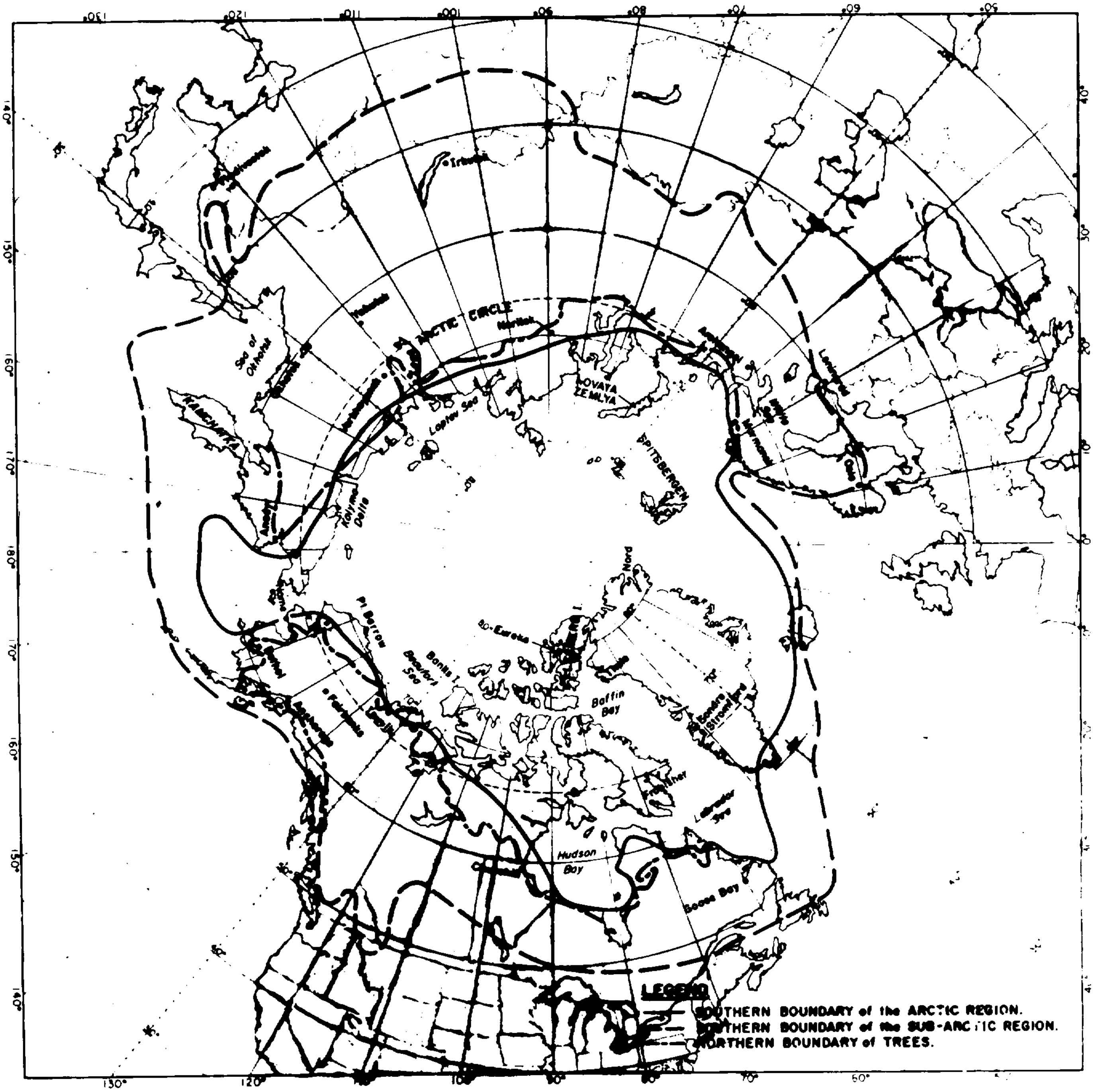
b. Icing on structures, vehicles and aircraft can be a serious problem in some parts of the Arctic and Subarctic, particularly in coastal areas near open water.

c. Snow cover may be a factor in planning field activities. Figures 2-6 and 2-7 provide measures of the snow cover season. Over large areas of the Arctic and Subarctic the mean depth of snow at the end of the month with maximum seasonal snow depth may not exceed about 2 to 2'1/ feet. For some areas the value may be as little as about 10 inches, and for others it may be several feet. Absolute maximum values may exceed the mean by about half.

d. Extreme local variations precluded state-wide mapping of ground snow loads for Alaska. Design snow loads for specific sites should only be adopted after consideration of local conditions. Maximum snow loads may vary not only with snow cover depths but also with regional and seasonal variations in snow cover density. The general variation of maximum snow load on the ground in Canada is illustrated in figure 2-8. Differences in elevation and in topographic position, as well as details of the engineering feature itself, can produce substantial differences in effective maximum snow loads.

2-4. Ice cover

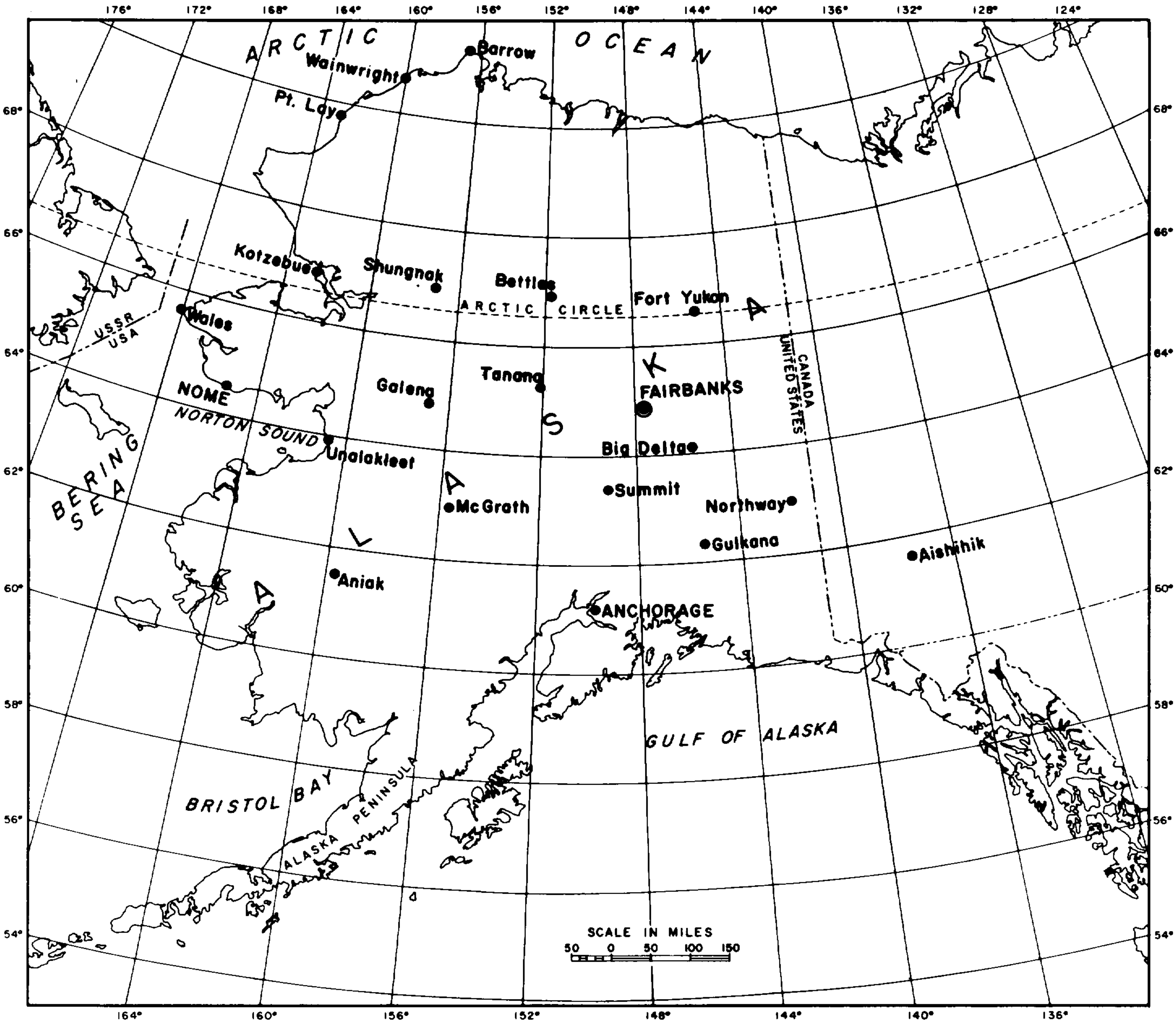
The freezing of lakes, rivers and coastal waters in winter can be a major controlling factor in the scheduling and effectiveness of field activities in the Arctic and Subarctic. Waterways that can be used for boats or float-equipped aircraft in the summer become unusable for these vehicles when freezeup starts in the period of September to November. Several weeks are then required before the ice becomes thick enough to support other types of vehicles. During the winter, ice surfaces can often be extremely valuable as aircraft



U.S. Army Corps of Engineers

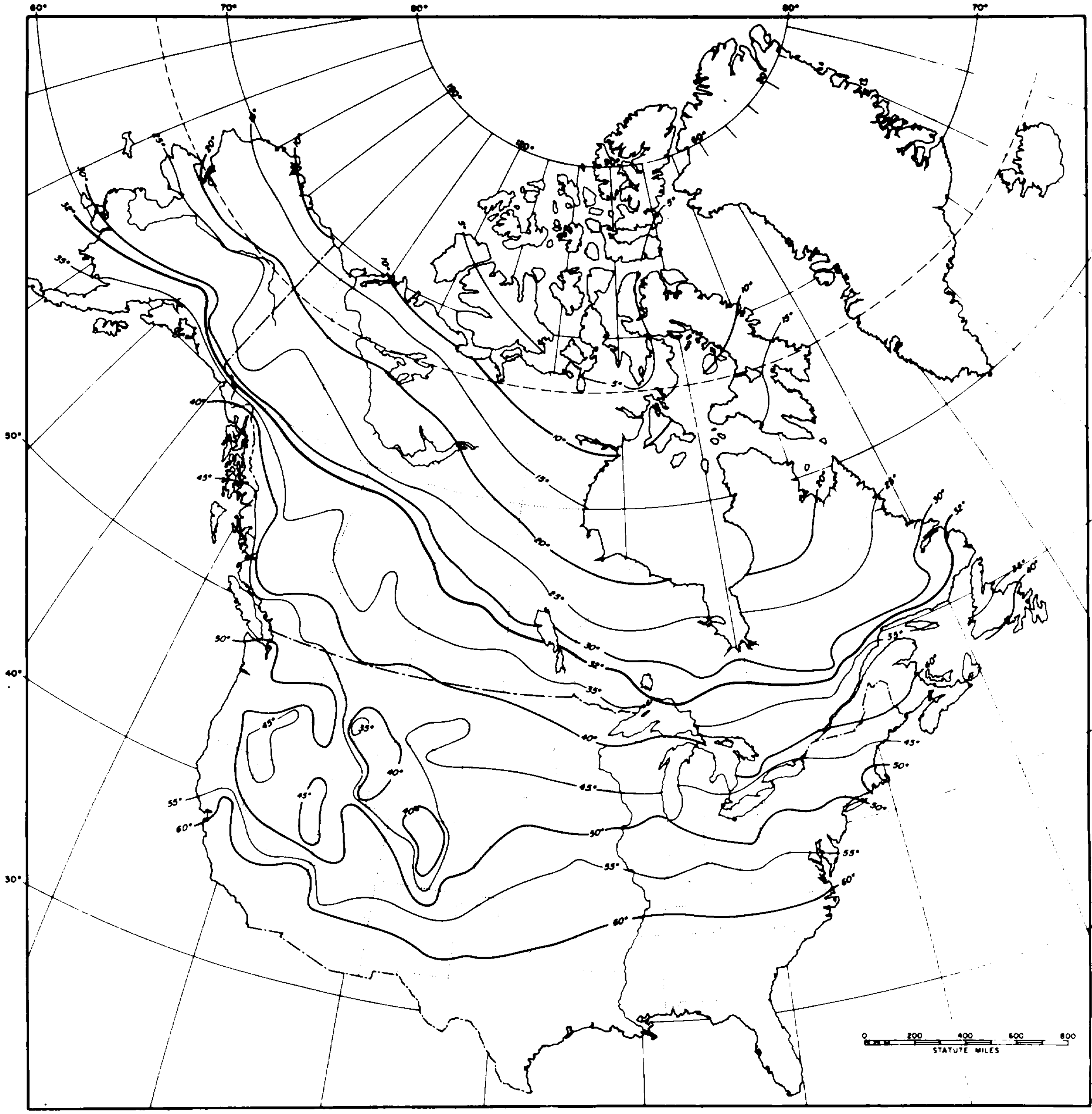
Figure 2-1. Northern cold regions: polar limits and zones.

landing areas and as smooth, obstruction-free surfaces for tractor-trains and other forms of surface transportation. Ice may be between 4 and 8 feet thick approximately between 1 April and 1 June and may remain capable of carrying loads for as many as 3 weeks after the start of surface thaw before becoming unsafe. Then there is another period of up to several weeks when the water body cannot be used for any form of transportation until the ice has melted or broken up and disappeared. Ice bearing capacity is affected by many variables such as ice thickness, temperature and quality; snow cover; type, speed, spacing and number of repetitions of moving loads; length of time of stationary loading; depth of water; presence of open cracks or zones of pressure buckling; and presence of springs, seepage inflow and currents. There is an approximate boundary between failure and safety for these conditions. For example, to ensure safe movement of single vehicles crossing freshwater (lake or river) ice at temperatures below 32°F, the formula P



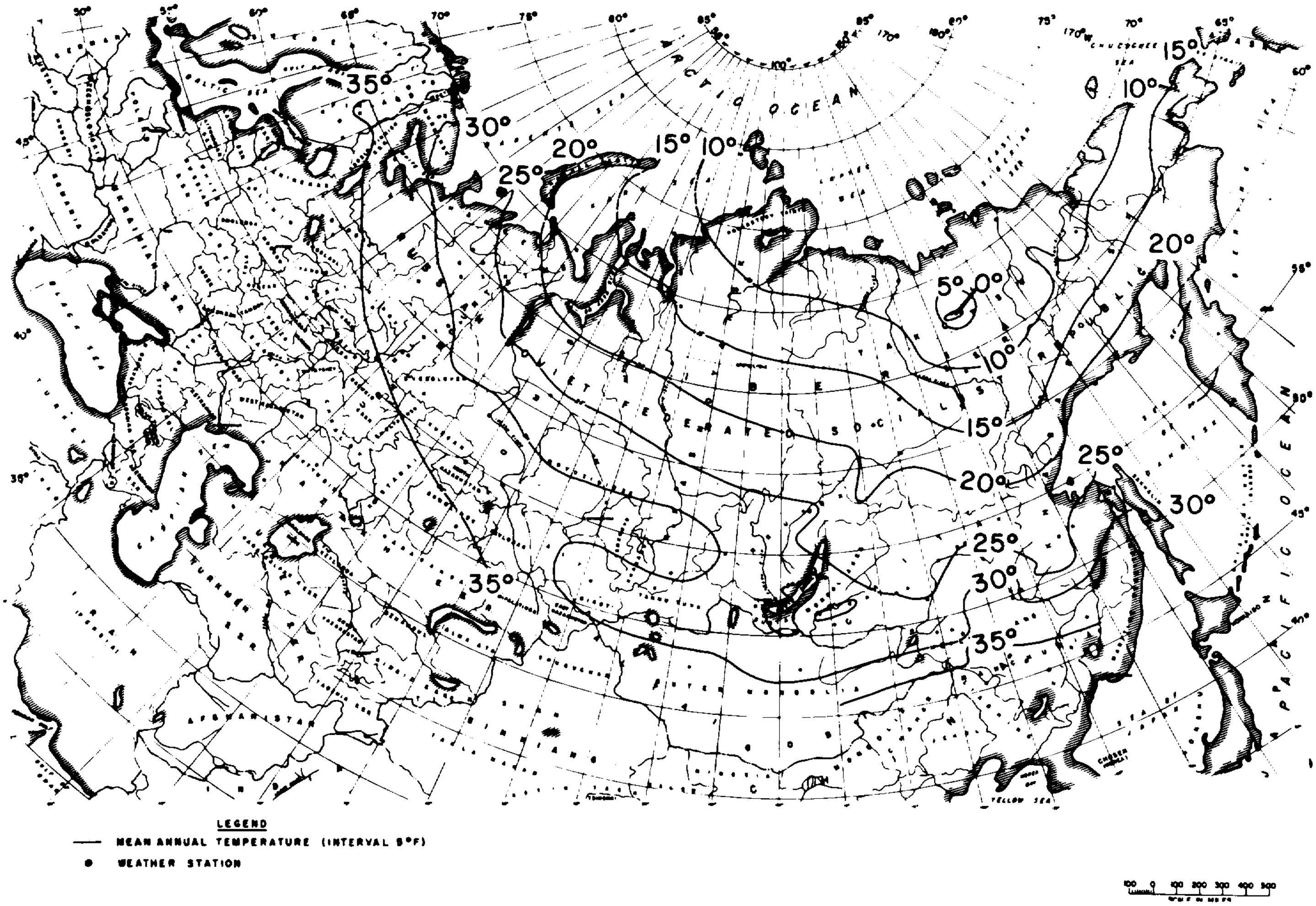
U.S. Army Corps of Engineers

Figure 2-2. Locations of observation stations in Alaska and Canada.



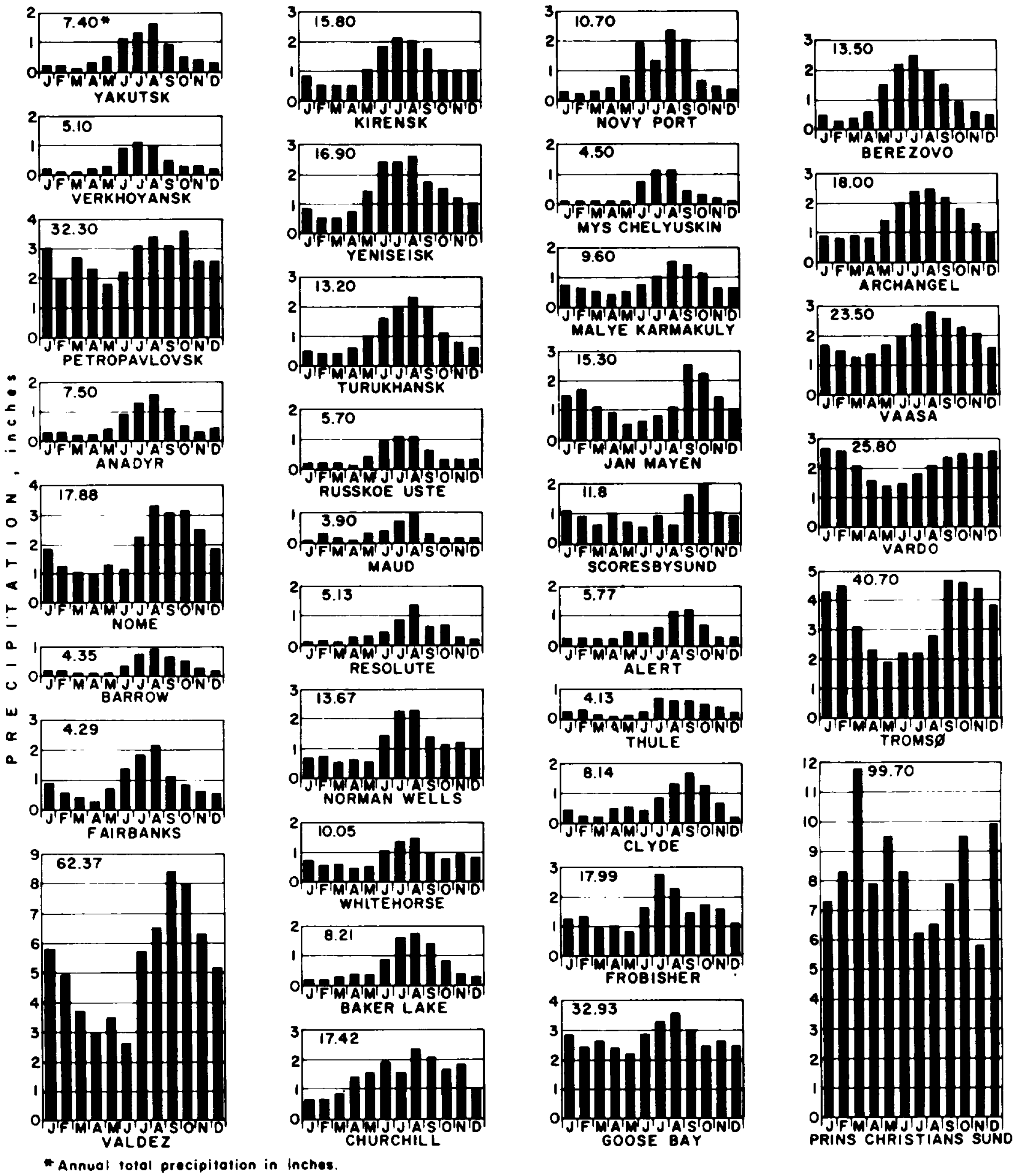
U.S. Army Corps of Engineers

Figure 2-3. Distribution of mean annual air temperature (° F) in North America.



U.S. Army Corps of Engineers

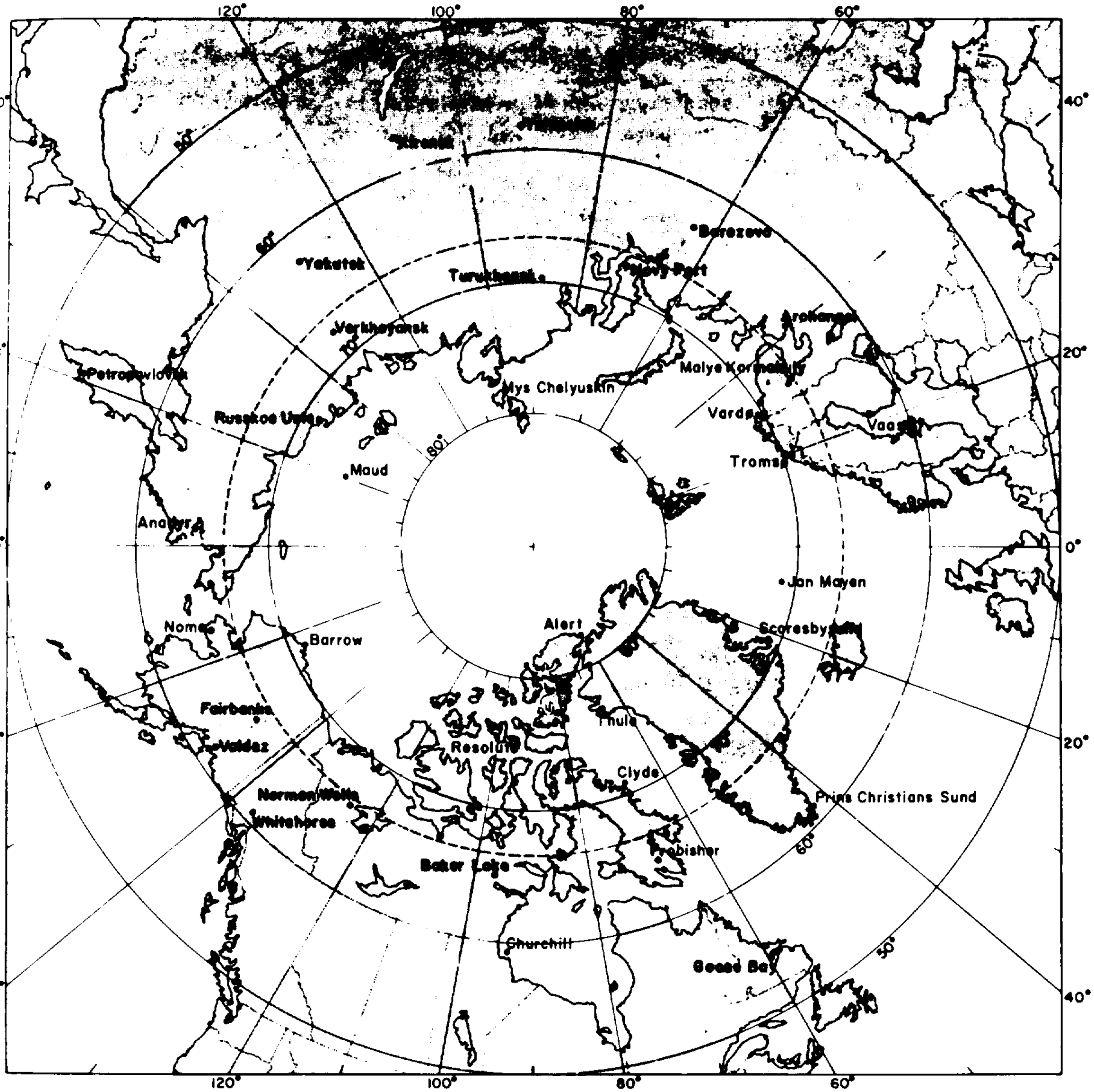
Figure 2-4. Distribution of mean annual air temperature (° F) in northern Eurasia.



U.S. Army Corps of Engineers

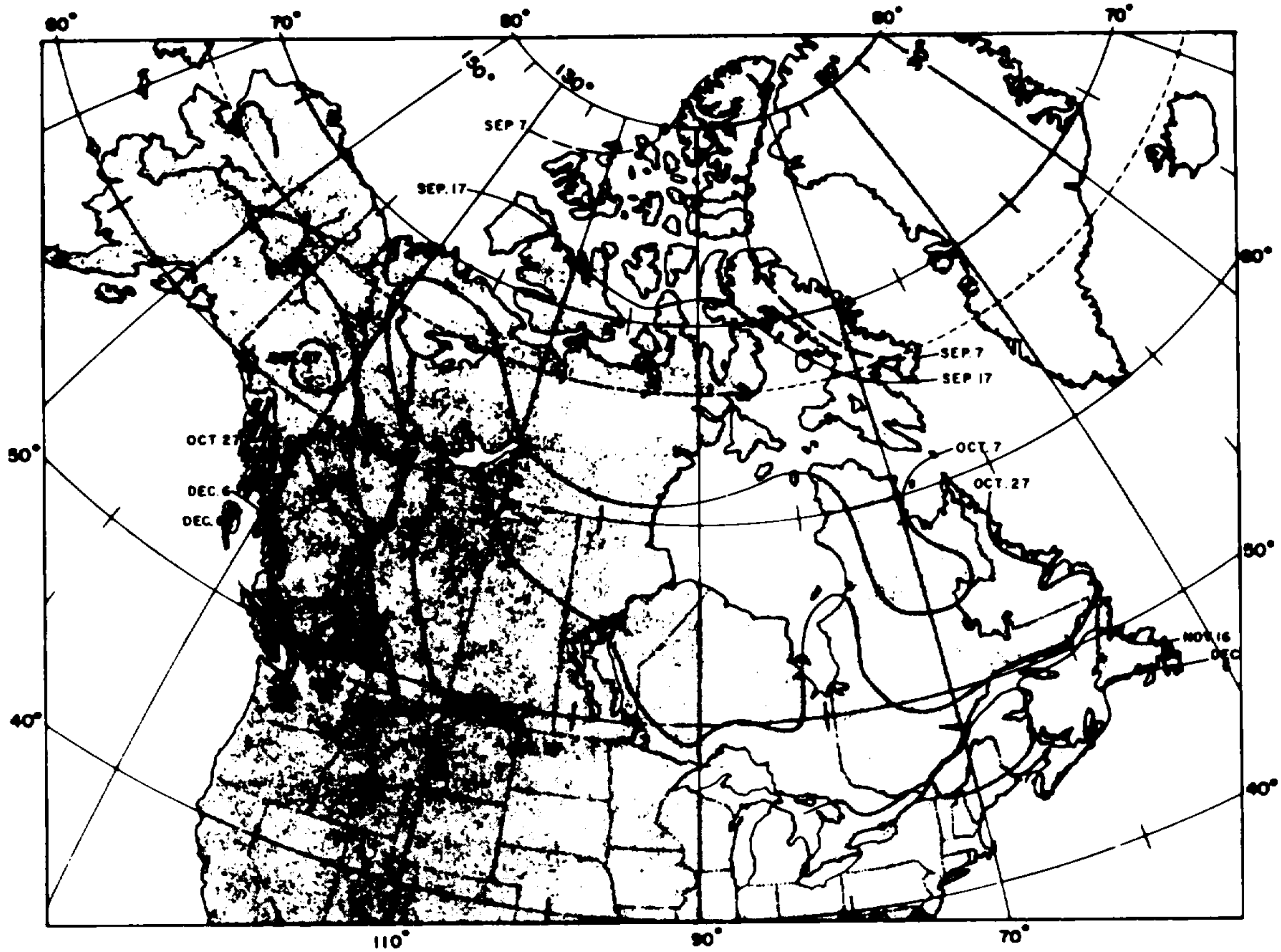
Note: Snowfall has been reduced to water equivalent, 10 inches of snow = 1 inch of water.

Figure 2-5a. Mean monthly and annual precipitation at selected stations.



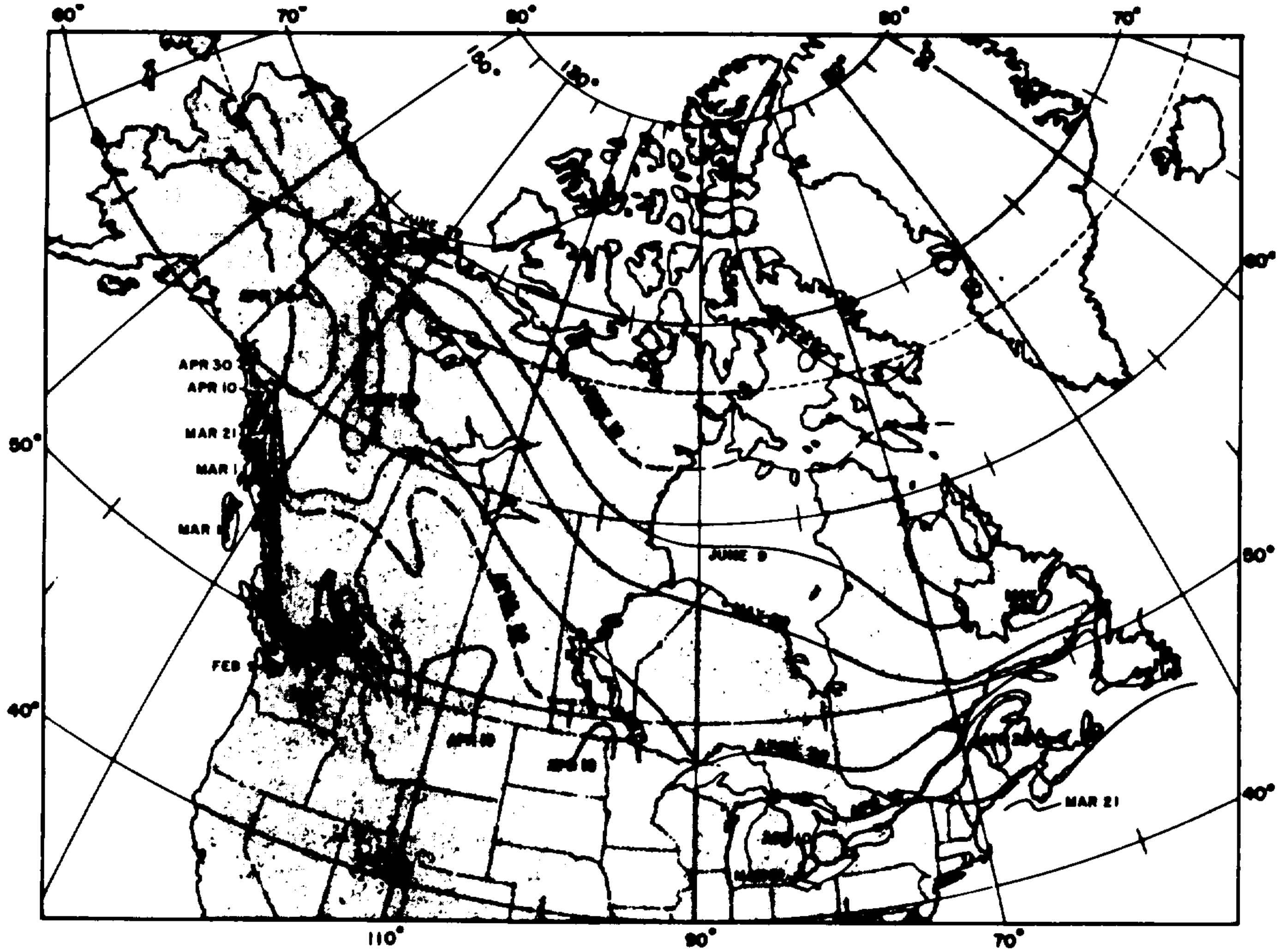
U.S. Army Corps of Engineers

Figure 2-5b Location of stations.



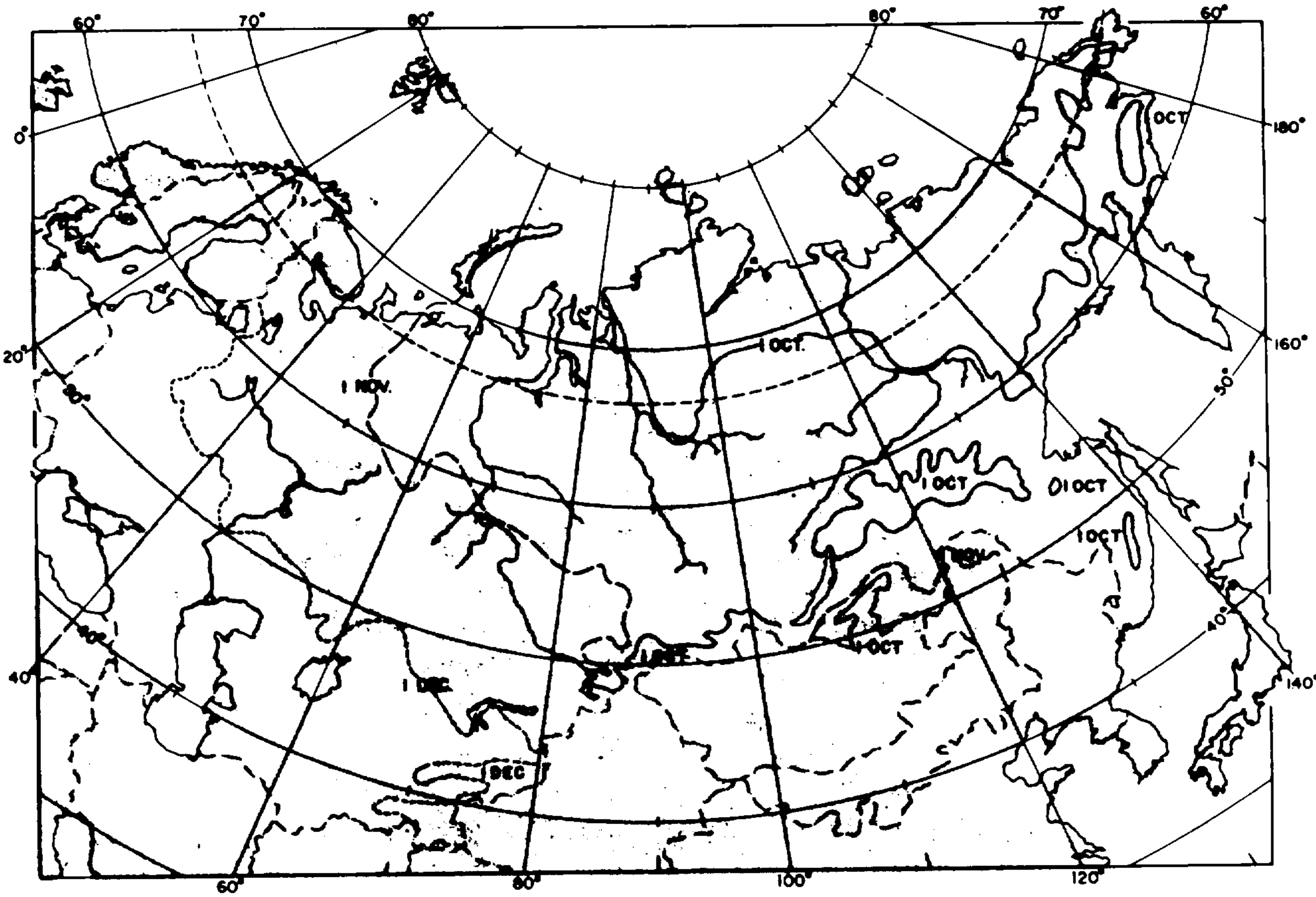
U.S. Army Corps of Engineers

Figure 2-6a. Snow cover of 1 inch or more in Canada - Mean annual date of first snow cover.



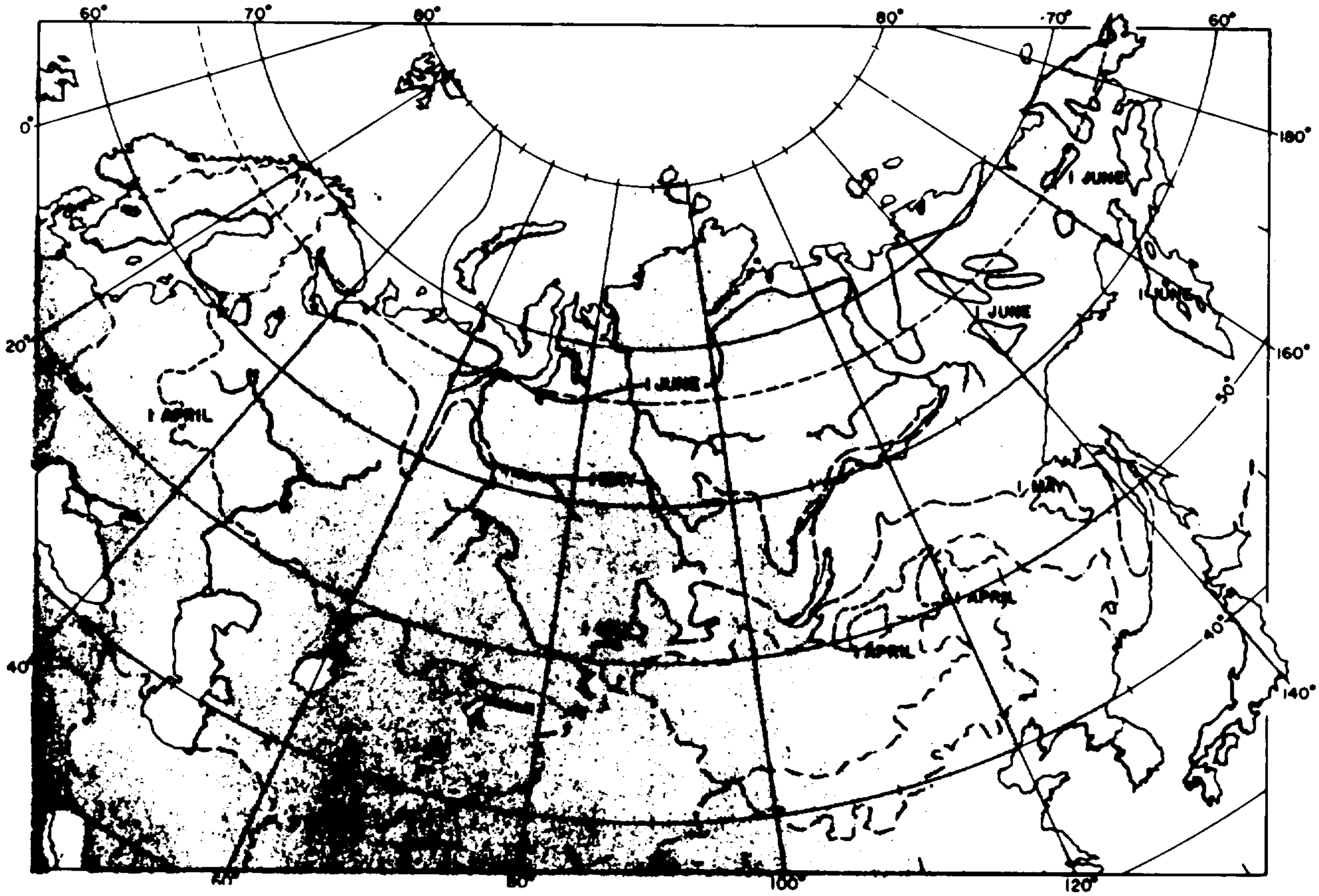
U.S. Army Corps of Engineers

Figure 2-6b. Snow cover of 1 inch or more in Canada - Mean annual date of last snow cover.



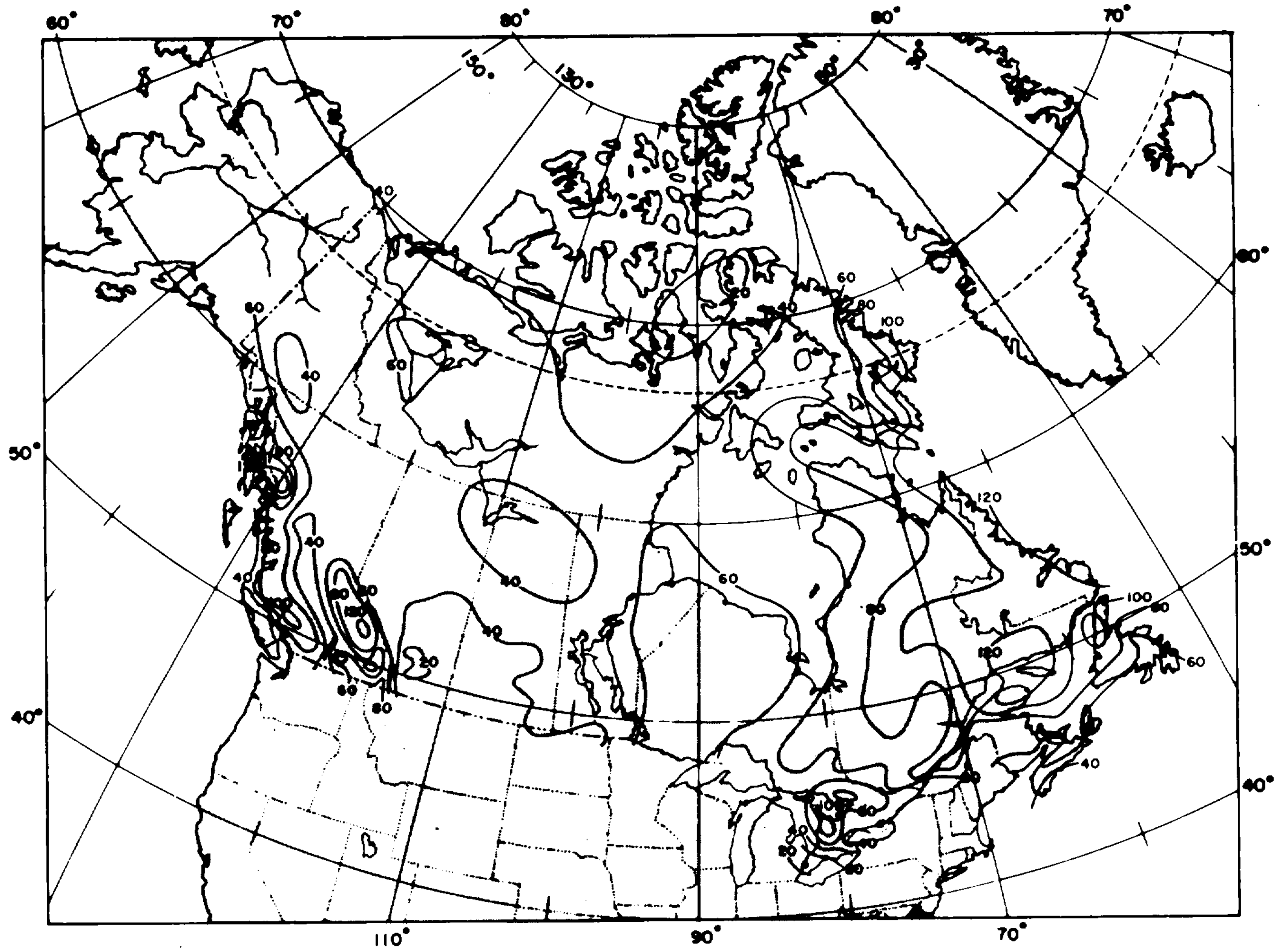
U.S. Army Corps of Engineers

Figure 2-7a. Stable snow cover, USSR - Average dates of formation.



U.S. Army Corps of Engineers

Figure 2-7b. Stable snow cover, USSR - Average dates of destruction.



U.S. Army Corps of Engineers

Figure 2-8. General variation in maximum snow load (lb/ft^2) on the ground in Canada.

= $h^2/16$ can be used as a rough guide (P is in tons and h is in inches of solid, clear ice). Table 2-1 is a slight refinement over the above formula for short-term loading. Solid, clear, freshwater ice has no air bubbles that might reduce strength. Ice containing air bubbles ("snow ice," often formed by the freezing of water soaked snow) is not as strong as clear ice. To account for the reduced strength of snow ice, 1 inch of snow ice is equivalent to only 1k inch of clear ice. If any substantial operation involving loading of floating ice is contemplated, guidance should be requested from the U.S. Army Cold Regions Research and Engineering Laboratory in Hanover, New Hampshire.

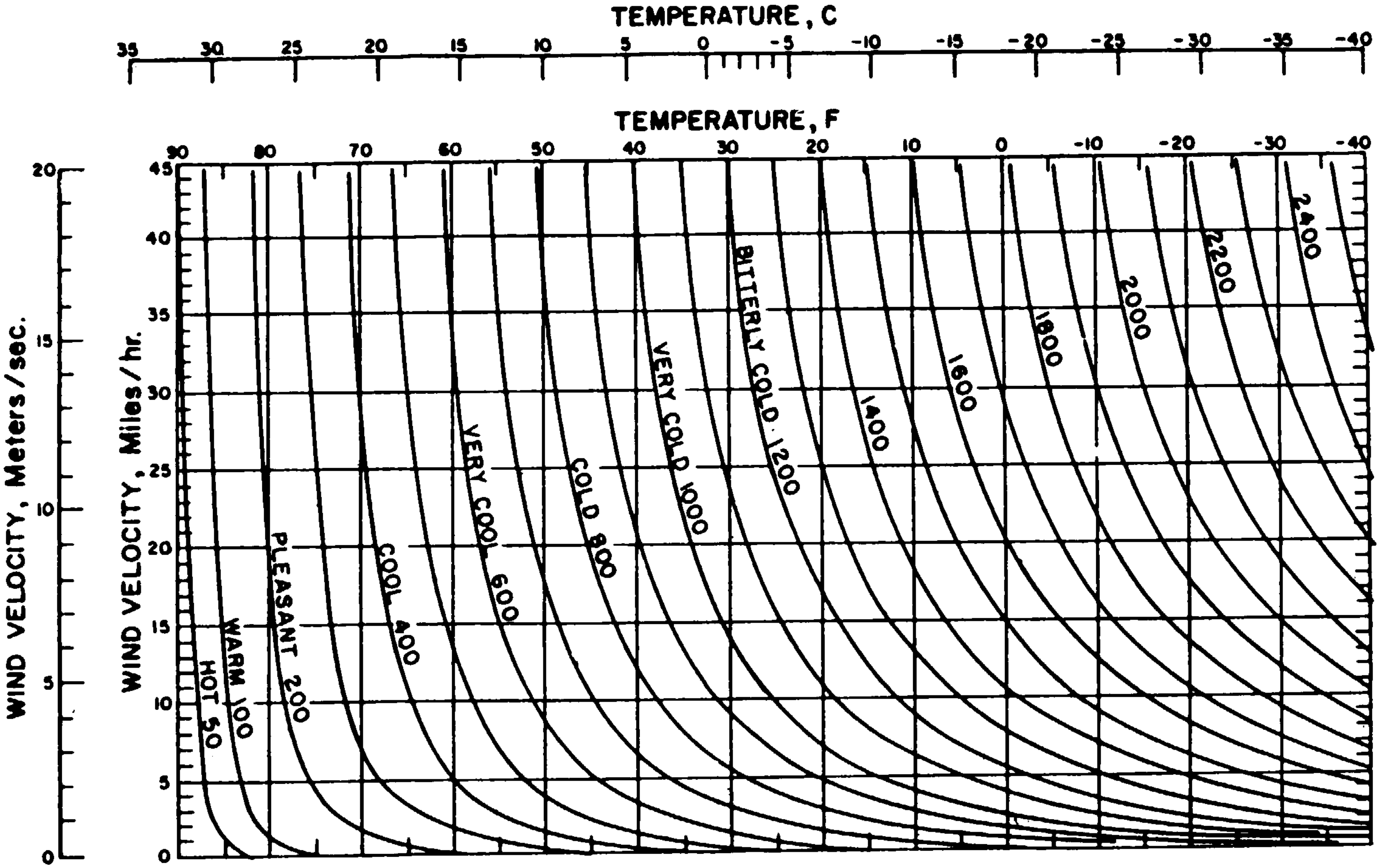
Table 2-1 Approximate short-term or moving load-carrying capacity of solid, clear, fresh water Ice (see text for snow ice).

Type of vehicle	Total weight (tons)	Necessary ice thickness (in inches) at average ambient temperatures for three days: 32° to 20°F	15°F and lower	Distance between vehicles (ft)
Tracked	6	10	9	50
	10	12	11	65
	16	16	14	80
	20	18	16	80
	25	20	18	100
	30	22	19	115
	40	25	22	130
	50	27	25	130
	60	30	28	150
Wheeled	2	7	7	50
	4	9	8	50
	6	12	11	65
	8	13	12	105
	10	15	14	115

NOTE: When the air temperature has been 32°F or higher for a few days, the ice should be considered unsafe for any load.

2-5. Wind and wind chill

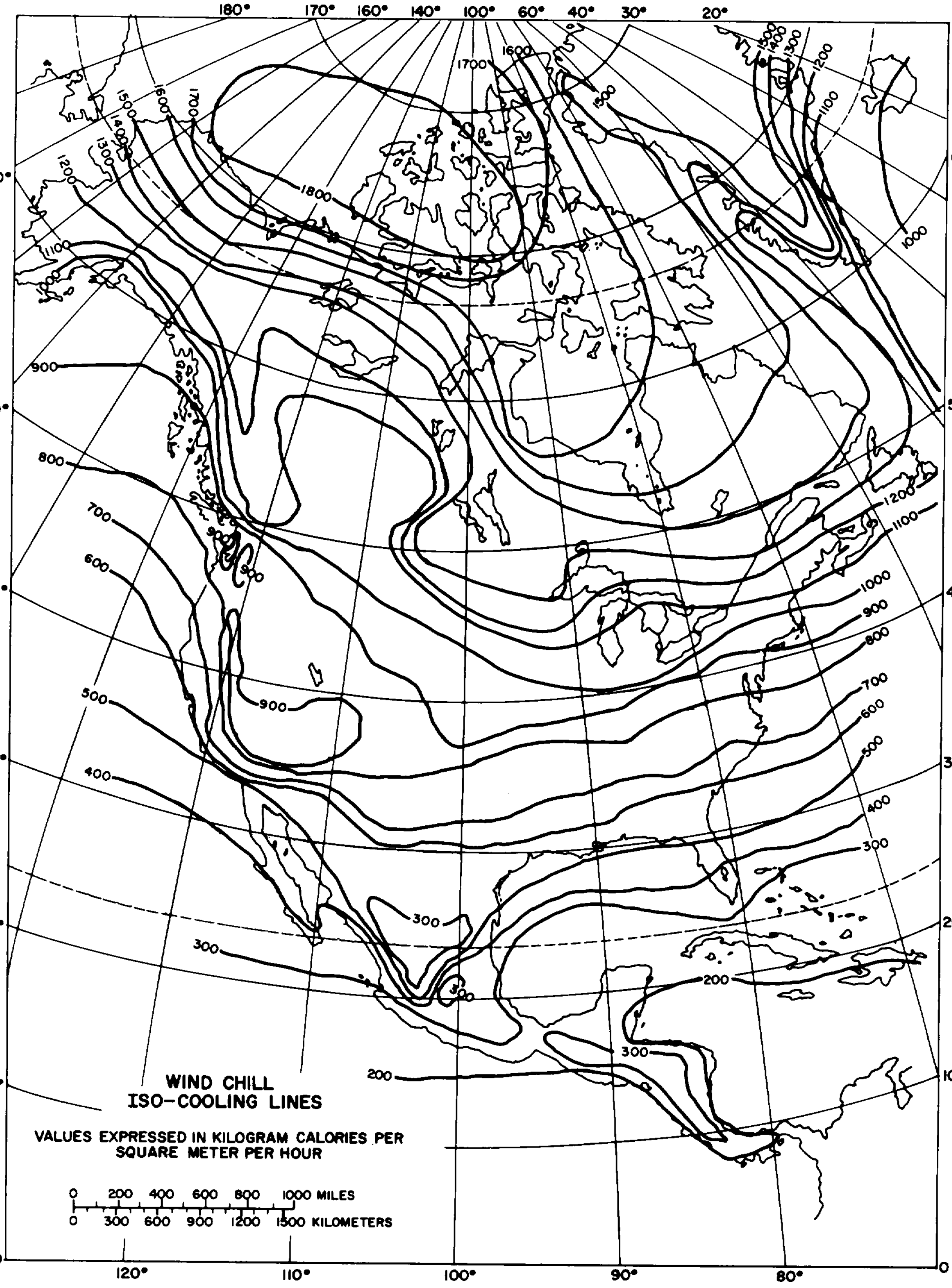
In many parts of the Arctic and Subarctic, where pressure gradients tend to be weak and temperature inversions are common, surface winds may normally be fairly low. Where pressure gradients are more marked, however, as in areas near seacoasts, and in and near mountains, strong winds may be quite common and wind speeds can attain hurricane velocities. For example, a maximum estimated wind gust in winter of 130 miles per hour has been reported for Kotzebue, Alaska. The possibility of strong katabatic winds that may be concentrated in valley outlets should be considered in site selection. If strong winds are possible, they may especially affect outdoor activities during the colder months. Worker efficiency decreases with lowering of air temperatures (about 2 percent per degree below 0°F), but wind significantly increases this effect, as shown by the wind-chill chart, figure 2-9. Distribution of January wind-chill values in North America is shown in figure 2-10. Information on the effects of various levels of wind-chill upon persons working outdoors is given in table 2-2.



Cooling is expressed in kilogram calories per square meter per hour for various temperatures and wind velocities. The cooling rate is based upon a body at a neutral skin temperature of 33 C. (91.4 F.). When dry cooling rate is less than the rate of body heat production, excess heat is removed by vaporization. Under conditions of bright sunshine, cooling is reduced by about 200 calories. Expressions of relative comfort are based upon an individual in a state of inactivity.

U.S. Army Corps of Engineers

Figure 2-9. Dry-shade atmospheric cooling (wind-chill values).



U.S. Army Corps of Engineers

Figure 2-10. Typical January wind-chill values for North America.

Table 2-2. Stages of relative human comfort and the environmental effects of atmospheric cooling.

Wind-chill factor		
Btu/ft^{2}hr	Kg cal/m^{2}hr	Relative comfort
220	600	Conditions considered as comfortable when people are dressed in wool underwear, socks, mitts, ski boots, ski headband and thin cotton windbreaker suits, and while skiing over snow at about 3 mph(metabolic output about 200 kg cal/m^{2}hr).
370	1000	Pleasant conditions for travel cease on foggy ant overcast days.
440	1200	Pleasant conditions for travel cease on clear sunlit (lays.
520	1400	Freezing of human flesh begins, depending upon the degree of activity, the amount of solar radiation, and the character of the skin and circulation. Average maximum limit of cooling during November, December and January. At temperatures above ,5° F these conditions are accompanied by winds approaching blizzard force.
590	1600	Travel and life in temporary shelter very disagreeable.
700	1900	Conditions reached in the darkness of mid-winter. Exposed areas of face freeze in leas than a minute for the average individual. Travel dangerous.
850	2300	Exposed areas of the face freeze less than 1/2 minute for the average individual.

2-6. Visibility and natural illumination

Care should be taken in siting projects to take into account the possibility of local adverse weather conditions. Visibility problems may arise, for example, from local fogs that form over nearby bodies of water. Ice fog and blowing snow can cause severe reductions in visibility in the winter months, compounded by the shortage of natural illumination at that time. A "white-out," a condition where there is a lack of contrast between the sky and the snow surface, can hinder visibility considerably. Long hours of daylight and twilight provide maximum illumination for field activities during spring and summer, but in fall and winter the sun is very low or below the horizon. Figure 2-11 shows that at the North Pole the number of days in the year with continuous daylight is double the number with continuous darkness. Thus, the annual light conditions in these regions are not as poor as they are sometimes pictured to be. The consistently low elevation of the sun above the horizon when it is shining reduces its energy effectiveness but does help in judging surface conditions from the air because of the shadows cast by knolls, ridges and vegetation. During dark periods, the light of the full moon may be of help for some activities. The number of hours of daylight or of daylight plus twilight can be estimated from figure 2-12 or 2-13.

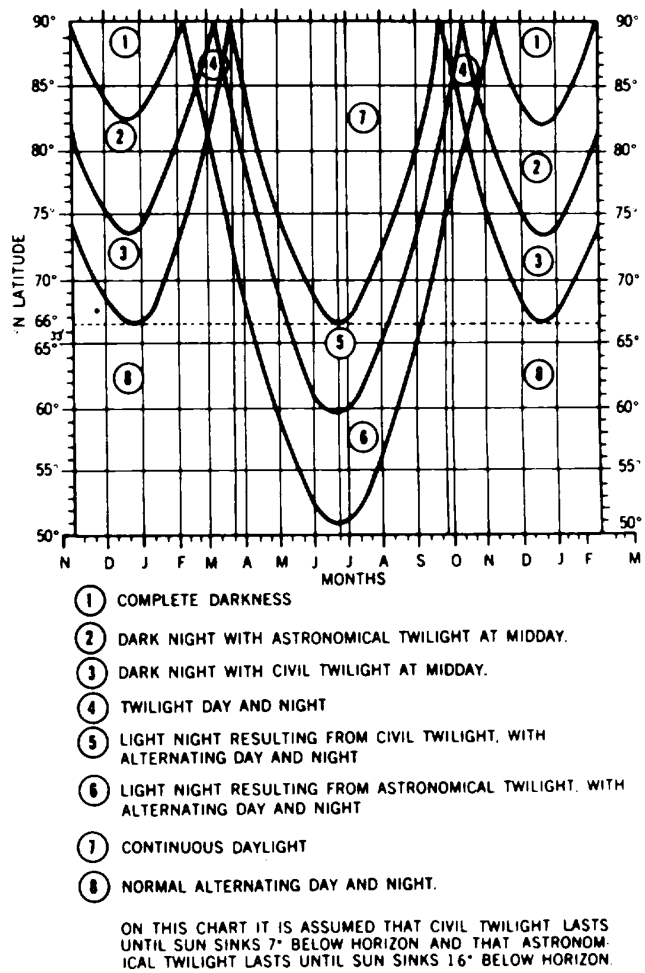
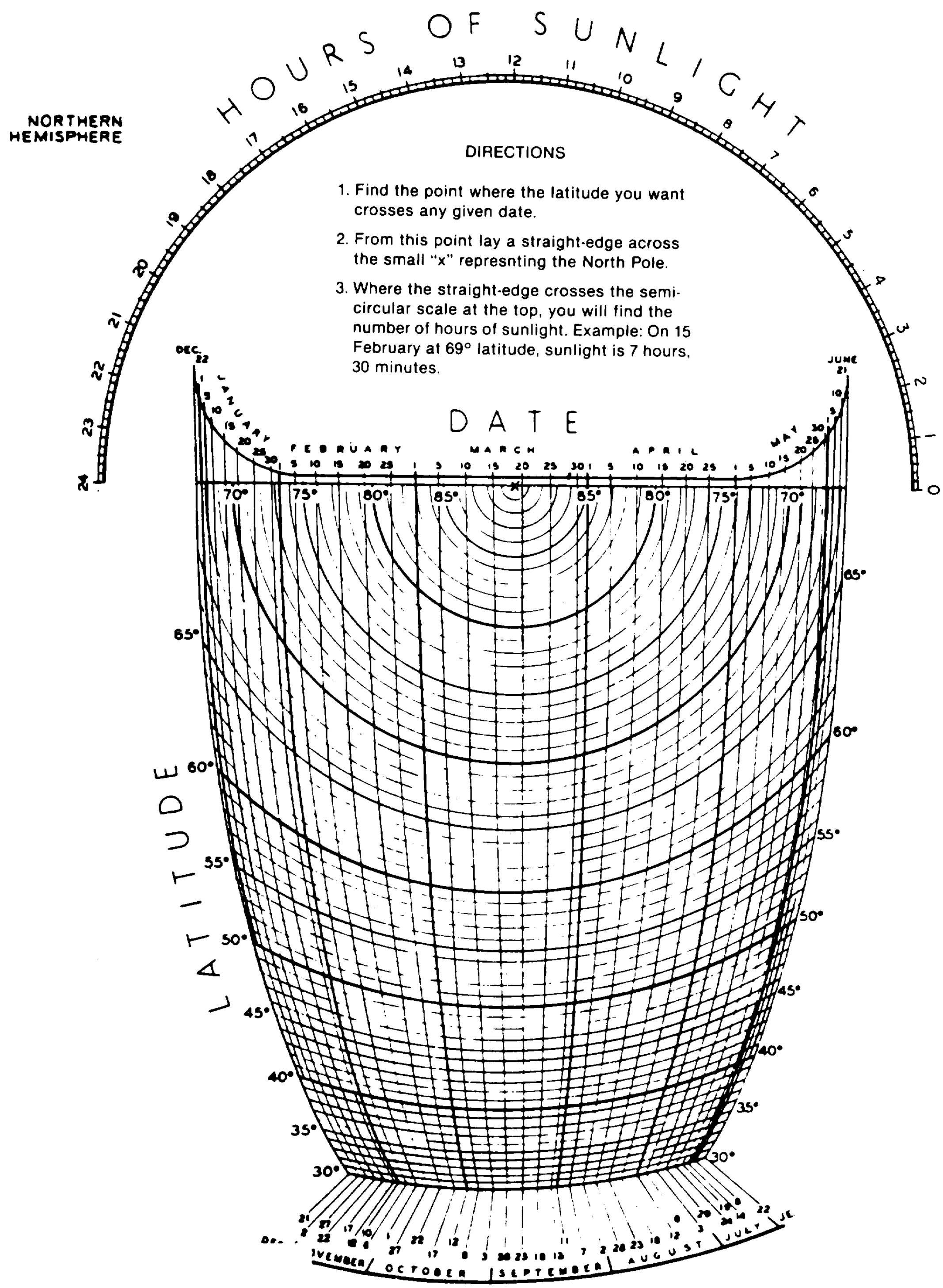


Figure 2-11. Solar illumination in the Arctic.

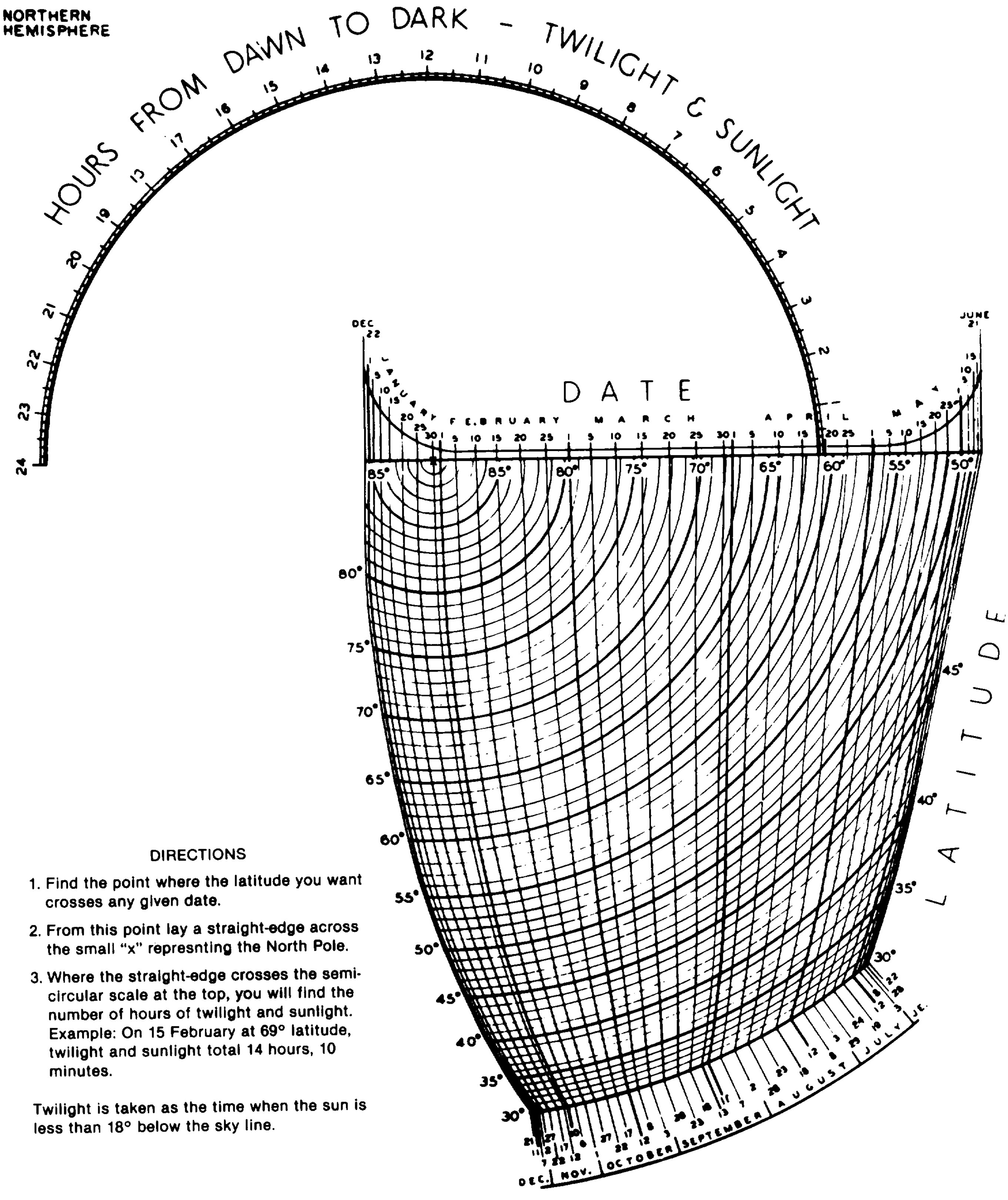
2-7. Vegetation

The three major types of vegetative cover in arctic and subarctic areas are tundra, muskeg and forest. Each of these represents a natural selection of species and the adaptation of vegetation to environmental factors such as soil and air temperatures, soil type,. drainage, depth of active layer over permafrost, etc. Vegetation can be of particular value in arctic and subarctic areas as an aid, in conjunction with other information



Reproduced from the Geographical Review, Vol. 33, 1943, by courtesy of the American Geographical Society.

Figure 2-12. Hours of sunlight



DIRECTIONS

1. Find the point where the latitude you want crosses any given date.
2. From this point lay a straight-edge across the small "x" represnting the North Pole.
3. Where the straight-edge crosses the semi-circular scale at the top, you will find the number of hours of twilight and sunlight. Example: On 15 February at 69° latitude, twilight and sunlight total 14 hours, 10 minutes.

Twilight is taken as the time when the sun is less than 18° below the sky line.

Reproduced from the Geographical Review, Vol. 33, 1943, by courtesy of the American Geographical Society.

Figure 2-13. Hours from dawn to dark - twilight and sunlight.

in interpretation of subsurface conditions. Because relationships between vegetation and subsurface conditions determined in one geographical area do not necessarily apply in an environmentally different area, a specific correlation should be established, verified, or known in any substantially different geographical area in which such information may be used.

2-8. Special surficial features and markings

Characteristic features and markings are produced on the ground in northern regions by permafrost degradation, frost action, mass wasting (i.e. creep, frost creep and frost sloughing) and other natural phenomena. These features include solifluction markings, pingos, thermokarst depressions and patterned ground. They can serve as important indicators of ground conditions, including the likelihood of the presence of permafrost and ground ice.

2-9. Seismic activity

Construction in the Arctic and Subarctic should be designed for seismic forces where required by the probability, in severity, frequency and potential damage, of seismic ground shaking or tsunamis (seismic sea waves). This is in addition to design for dead, live, snow and wind structural loads. Though risk from earthquake-generated forces is not very high over much of the Arctic and Subarctic, risk of major or great damage exists in certain areas, such as in Alaska, south of about Fairbanks. TM 5-809-10/NAV FAC P-355/AFM 88-3, Chap. 13 provides criteria and guidance for seismic design.

2-10. Graphic summaries

a. To aid in understanding the environmental conditions at specific locations and their variations through the seasons, graphic summaries such as the one for Barrow, Alaska, shown in figure 2-14 (fold-out located in back of manual), are useful.

b. Seismic probability, snow load and other design data may also be summarized on a regional basis to provide engineers with values to be adopted in design work.